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Socio-economic impact of Foot-and-Mouth Disease outbreaks and control measures: An analysis of Mongolian outbreaks in 2017

Georgina Limon[1] | Gerelmaa Ulziibat[2] | Batkhuyag Sandag[3] | Serjmyadag Dorj[2] | Dulam Purevtseren[2] | Bodisaikhan Khishgee[3] | Ganzorig Basan[2] | Tsolmon Bandi[3] | Sodnomdarjaa Ruuragch[2] | Mieghan Bruce[4] | Jonathan Rushton[5] | Philippa M. Beard[1,6] | Nicholas A. Lyons[1,7]

[1]The Pirbright Institute, Pirbright, UK
[2]State Central Veterinary Laboratory, Ulaanbaatar, Mongolia
[3]General Agency for Veterinary Services, Ulaanbaatar, Mongolia
[4]School of Veterinary Medicine, College of Science, Health, Engineering and Education, Murdoch University, Murdoch, WA, Australia
[5]Institute of Infection and Global Health, University of Liverpool, Liverpool, UK
[6]The Roslin Institute and Royal (Dick) School of Veterinary Studies, Midlothian, UK
[7]European Commission for the Control of Foot-and-Mouth Disease (EuFMD), Food and Agriculture Organisation of the United Nations, Rome, Italy

Correspondence
Georgina Limon, The Pirbright Institute, Pirbright, UK.
Email: georgina.limon-vega@pirbright.ac.uk

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Abstract

Mongolia is a large landlocked country in Central Asia and has one of the highest per capita livestock ratios in the world. During 2017, reported foot-and-mouth disease (FMD) outbreaks in Mongolia increased considerably, prompting widespread disease control measures. This study estimates the socio-economic impact of FMD and subsequent control measures on Mongolian herders. The analysis encompassed quantification of the impact on subsistence farmers' livelihoods and food security and estimation of the national-level gross losses due to reaction and expenditure during 2017. Data were collected from 112 herders across eight provinces that reported disease. Seventy of these herders had cases of FMD, while 42 did not have FMD in their animals but were within quarantine zones. Overall, 86/112 herders reported not drinking milk for a period of time and 38/112 reduced their meat consumption. Furthermore, 55 herders (49.1%) had to borrow money to buy food, medicines and/or pay bills or bank loans. Among herders with FMD cases, the median attack rate was 31.7%, 3.8% and 0.59% in cattle, sheep and goats, respectively, with important differences across provinces. Herders with clinical cases before the winter had higher odds of reporting a reduction in their meat consumption. National-level gross losses due to FMD in 2017 were estimated using government data. The estimate of gross economic loss was 18.4 billion Mongolian-tugriks (US$7.35 million) which equates to approximately 0.65% of the Mongolian GDP. The FMD outbreaks combined with current control measures have negatively impacted herders' livelihoods (including herders with and without cases of FMD) which are likely to reduce stakeholder advocacy. Possible strategies that could be employed to ameliorate the negative effects of the current control policy were identified. The findings and approach are relevant to other FMD endemic regions aiming to control the disease.

Limon and Ulziibat contributed equally to this work.

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KEYWORDS
FMD control, herders, Mongolia, outbreak, socio-economic impact

1 | INTRODUCTION

Foot-and-mouth disease (FMD) is a viral disease that has negative impacts on farmers and stakeholders along the value chain in endemic countries and when introduced into previously free countries. Impacts encompass direct losses that limit livestock production (such as decreased milk production, lower weight gains, decreased fertility and increased mortality mainly in young animals), as well as costs associated with the response to disease or infection (such as treatments, vaccination, movement controls and stamping out) (Knight-Jones & Rushton, 2013). Countries with endemic FMD are denied access to some potentially lucrative export markets for livestock and animal products, giving governments a clear incentive to chain resources to control the disease. It is often assumed that by controlling the disease and acquiring the World Organization for Animal Health (OIE) 'free without vaccination' status, all animal holders (regardless of the production system, size, and access to markets) would benefit, either by increasing their income or increasing availability of animal-source food (ASF), such as milk and meat, in the household (FAO, 2011; FAO & OIE, 2012). However, the benefits of controlling the disease in low- and middle-income countries (LMIC) are complex and not well quantified (Knight-Jones, McLaws, & Rushton, 2016; Knight-Jones, Robinson, et al., 2016; Limon et al., 2017). Furthermore, the impact of FMD and consequences of the control programmes on animal holders' livelihoods and food security is rarely explored. Studies have focused on quantifying the impact of the disease in mixed crop-livestock systems in Africa and Asia, and large-scale commercial or pastoral systems in Africa (Jemberu, Mounts, Woldehanna, & Hogeveen, 2014; Lyons, Alexander, et al., 2015; Lyons, Stärk, et al., 2015; Nampanya et al., 2015; Perry, Gleeson, Khounsey, Bounma, & Blacksell, 2002; Young, Suon, Andrews, Henry, & Windsor, 2013). However, the indirect impact of FMD control measures in settings where animal holders' diet is based on ASF has not been assessed.

Mongolia is a large landlocked country in Central Asia, bordered by Russia to the North and China to the South, East and West (Figure 1a). Mountain chains dominate the northern and western part of Mongolia, with valley areas between and around the mountains. In the Northern part, mountains include some of the taiga forest followed by a mix of tundra and steppe. To the south and east is an extensive area of steppe followed by a steppe-desert transition zone in the south (Figure 1b). The southern part of Mongolia is dominated by the vast Gobi desert which extends into northern China.

Mongolia has one of the highest per capita livestock ratios in the world, with a human population of 3.2 million and 4.3 million cattle, 30.1 million sheep, 27.3 million goats and 434 thousand camels (Mongolian Statistical Information Service, 2017) with a quarter of

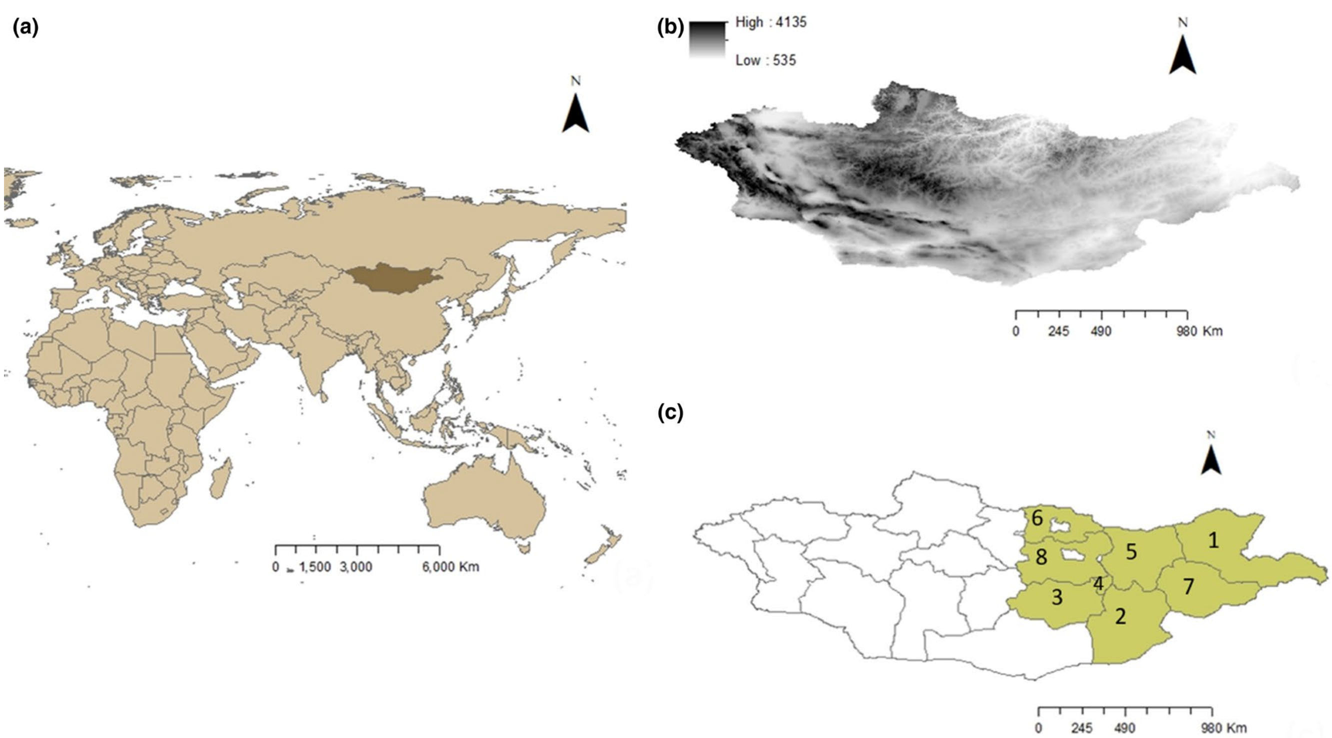

FIGURE 1 Geographic location of the study area (a) location of Mongolia (dark brown) in Central Asia; (b) altitude across Mongolia; (c) provinces affected during 2017 (in alphabetical order): (1) Dornod, (2) Dornogavi, (3) Dundgovi, (4) Govisümber, (5) Khentii; (6) Selenge, (7) Sükhbaatar and (8) Tuv

households owning livestock, and a quarter of people employed in the agricultural sector which is dominated by livestock production (Erdenesan, 2016). Livestock are raised predominantly by nomadic herders with production based on traditional herding practices. Herders move location each season and are typically placed kilometres apart from one another leaving them very geographically isolated.

The rural Mongolian diet is influenced by the extreme continental climate, isolation and nomadic lifestyle, and it is heavily reliant on animal protein and fat (dried meat mostly in the winter and meat and dairy products during the summer) (Jamiyan, 2017b). Although alternative staples and vegetables have been introduced over the years, these are mainly consumed in urban areas. Food security is a key component of the aim to achieve 'zero hunger' (one of the United Nation's sustainable development goals) and has four core dimensions: availability, access, stability and utilization (UNDP, 2015; World food summit, 1996). In rural Mongolia as in other LMIC, food availability, access and stability depend to a great extent on household-level production, which can be compromised by suboptimal animal health or abrupt changes in herd structure (Rushton, Thornton, & Otte, 1999). In recent years, Mongolia has implemented a series of programmes to reduce food insecurity and improve the nutritional status of the Mongolian population, with targeted social programs to reduce vulnerability to seasonal food shortages (Jamiyan, 2017a).

Mongolia has a very long and sparsely populated land border which makes it vulnerable to transboundary animal diseases. In the past 5 years, Mongolia has been affected by peste des petits ruminants (PPR) for the first time (2016–2017), sheep and goat pox (SGP) (2008–2009 after 26 years without the disease and 2016) and foot-and-mouth disease (FMD) (WAHID-OIE, 2017).

Reports of FMD in Mongolia increased in January 2017 compared with previous 12 years (Figure S1); with outbreaks of serotype O affecting 810 herders between January and December 2017 in 8 provinces in the Eastern part of the country. Species affected included cattle, sheep, goats and camels. Up to 9 outbreaks (defined as all herders affected during the same quarantine period following outbreak investigation) were reported each month, with more outbreaks reported in the summer and winter periods compared to spring and autumn periods (Figure S2). The current national FMD control strategy in Mongolia consists of vaccination twice a year in high-risk areas, modified stamping out (i.e. only destroying animals with clinical signs) and movement controls. Following a report of an animal with clinical signs suspected as FMD, a 10 km quarantine zone is put in place and an outbreak investigation begins. The size of the quarantine zone might vary depending on the location and natural barriers. Animals with clinical signs are destroyed and farmers receive compensation worth 90% of the commercial value of the animals culled. Once the last animal is destroyed, a 28-day quarantine period begins. During the outbreak investigation and quarantine period, no animals or people can move in or out of the quarantine zone. Once the quarantine period has concluded, the subsequent appearance of clinical signs of FMD in a herd is considered a new outbreak and a new investigation and quarantine period initiated.

Estimating the impact of animal disease and resultant control measures at both the national and herder levels provides information that can be used to guide future control policy and resource allocation for animal diseases. This study addresses the impact of FMD in Mongolia in 2017 by (a) assessing the socio-economic impact of FMD and the control measures on herders; and (b) estimating the national gross economic losses during 2017.

2 | MATERIAL AND METHOD

2.1 | Study settings

This study was conducted in eight Eastern provinces in Mongolia (Figure 1c). Mongolia is divided into 22 provinces (commonly known as aimags), 335 districts (also known as soums) and 1,800 sub-districts (also known as bags) which are the smallest administrative unit.

2.2 | Herder level

2.2.1 | Study design

Using official outbreak reports from the State Central Veterinary Laboratory (SCVL), ten herders affected with FMD were randomly selected in each affected province from outbreaks starting between January 2017 and December 2017 (Figure 1c). Five additional herders that were not affected but within these quarantine areas during the same period were also selected. Herders affected with FMD in January 2018, but during an outbreak commencing in 2017 were included in the sampling frame. For simplicity, selected herders affected by FMD will be referred to as 'affected herders' and herders not affected by FMD but within the quarantine zone will be referred to as 'quarantined herders'. For each selected herder, the aim of the study was explained and verbal consent to participate was obtained. If the number of affected herders in a given province was less than ten, all affected herders during the study period were surveyed. Similarly, if there were fewer than five quarantined herders, all available herders were visited.

2.2.2 | Data collection and questionnaire design

A standardized questionnaire was designed using an exploratory sequential approach (Creswell & Plano Clark, 2011). An initial questionnaire using a combination of closed and open-ended questions was designed based on authors' (GL, NAL) experiences and discussion with members of the SCVL. This questionnaire was piloted in four affected herders from one province (Tuv). Answers given by these four herders were discussed among the team members and used to modify the initial questions according to the local context

TABLE 1 Data collected as part of the herder survey and used for analysis

Survey Variables description	Possible answer	Data management for analysis Category
Province	List of names of the eight provinces that are part of the study	Dornod; Dornogovi; Dundgovi; Govisümber; Khentii; Selenge; Sükhbaatar; Tuv
Production system	Fixed location Nomadic	Sedentary Nomadic
Number of animals	Number of animals owned per specie (cattle, sheep, goats, camels)	Cattle; Sheep; Goats; Camels
Purpose(s) of keeping animals	Slaughter them and eat the meat at home Slaughter them at home and sell the meat Produce milk and consume it at home Produce milk and sell it Sell animals when money is needed Sell animals on regular basis (e.g. every summer, every month) Other (specify):	Source of meat for home consumption Selling meat to generate income Produce milk for home consumption Selling milk to generate income Selling live animals to generate income according to need Sell animals on regular basis
Herd affected with FMD or quarantined only	Affected with FMD Not affected with FMD but within the control zone	Affected herders Quarantined herder
Socio-economic impact		
Preventive measures to animals not affected	Kept animals isolated Herd treatment with antibiotics Herd treatment with other than antibiotics. Specify: Nothing Other (specify):	Kept animals isolated Treatment with antibiotics Using alternative approach (washing, disinfecting, fumigating) Did not apply any measure Vaccination (by the government)
Treatment details for those that applied treatment	Overall expenditure in Mongolian-tugriks (₮)	Treatment expenditure overall Treatment duration for those that treated with antibiotics
	Number of days treatment last	Treatment duration (days)
Plans to sell animals or animal products and could not sell because of the outbreak or control measures	Number of live animals that was planning to sell per species	Live cattle Live sheep Live goats Live camels — Planned to sell
	Litres of milk that was planning to sell per species	Litres of cattle milk (milk from other species was not reported)
	Kg cashmere	Kg cashmere
	Kg of wool	Kg of wool
Milk consumption affected by the outbreak or control measures	Did not drink any milk for a period of time (Yes/No) Specify length of time Drank less milk for a period of time (Yes/No) Specify length of time Purchased milk from elsewhere Specify length of time Litres bought Cost per litre in Mongolian-tugriks (₮)	Cease drinking milk for a period of time (Yes/No) Number of days not consuming milk Drank less milk for a period of time (Yes/No) Number of days consuming less milk Purchased milk from elsewhere Number of days purchasing milk Litres of milk bought Cost per litre of milk
Meat consumption affected by the outbreak or control measures	Did not eat any milk for a period of time (Yes/No) Specify length of time Ate less meat for a period of time (Yes/No) Specify length of time Purchased meat from elsewhere Specify length of time Kg bought Cost per kg in Mongolian-tugriks (₮) Other (specify)	Cease eating meat for a period of time (Yes/No) Number of days not consuming meat Ate less meat for a period of time (Yes/No) Number of days eating less meat Purchased meat from elsewhere Number of days purchasing meat Litres of milk bought Cost per kg meat Had dry meat stored
Purchasing before the outbreak.	Purchased meat before the outbreak (Yes/No) Purchased milk before the outbreak (Yes/No)	Purchased meat before the outbreak (Yes/No) Purchased milk before the outbreak (Yes/No)

(Continues)

TABLE 1 (Continued)

Survey Variables description	Possible answer	Data management for analysis Category	
Purchase of new animals to replace those that died or were culled	Replaced all of them Replaces some of them None Reasons for not replacing them (*open question*) Cost of replacement animals per species Mongolian-tugriks (₮)	Replaced all of them Replaces some of them None Lack of money Delays in receiving financial compensation Cost of replacement cattle, sheep and goats	
Other ways the outbreak or quarantine impact herders' family	Had to borrow money to buy food Had to borrow money to buy animals Had to borrow money to pay bills/ bank loans Had to borrow money to pay school fees Had to borrow money to buy medicines Extra payments for children accommodation during holidays Could not afford school fees School close during control measures were in place Unable to buy medicines for family members Could not visit family Could not receive visitors Family members could not get back Other specify:	Had to borrow money to buy food Had to borrow money to buy animals Had to borrow money to pay bills/ bank loans Had to borrow money to pay school fees Had to borrow money to buy medicines Extra payments for children accommodation during holidays Could not afford school fees School close during control measures were in place Unable to buy medicines Could not visit family Could not receive visitors Family members could not get back	
For herds affected only			
Beginning of the herd-case	Date the first animal presented clinical signs	Herd-case length	
End of the herd-case	Date the last animal was destroyed or died	Categorical ≤ 6 days; >6 days (based on median time)	
Animals affected	Number of animals with clinical signs per species	Number of animals with clinical signs	Cattle
Animals not affected	Number of animals without clinical signs per species	Number of animals without clinical sign	Sheep
Animals culled	Number of animals culled per species	Number of animals culled	Goats
Animals that died	Number of animals (with clinical signs) that died per species	Number of animals (with clinical signs) that died	Camels

and generate potential answers for each open question. This led to the creation of a multiple-choice questionnaire. For questions that were considered to have possible alternative answers, sufficient space for open text was included. The questionnaire was translated into Mongolian by one of the authors (GU) and entered into a mobile phone application (https://five.epicollect.net/) for data collection by government veterinarians of each province (between 4 and 8 veterinarians in each province). A summary of data collected and used for analysis is presented in Table 1. Copies of the questionnaire are available from the corresponding author upon request.

2.2.3 | Data analysis

Herds included in the study and epidemiological characteristics

Descriptive statistics were generated stratified by province, FMD status (affected herder versus quarantined herder) and species. Parameters estimated included the number of animals on the day of the survey (cattle, sheep, goats and camel), attack rate, case fatality rate and herd-case duration (the latter three parameters were for affected herds only). Attack rate was estimated as the number of animals with clinical signs divided by the sum of animals with clinical signs plus animals without clinical signs in the herd/flock stratified per species, age category and province. Case fatality rate was estimated as the number of animals that presented clinical signs and died divided by the number of animals with clinical signs during the outbreak period (Table S1). Herd-case duration was defined as the period between the day the first animal in the herd/flock showed clinical signs to the day the last animal affected showed clinical signs or was culled.

Fisher's exact or Pearson's chi-squared tests were used to determine the strength of association between the categorical outcomes of two groups, for example when comparing impact and coping strategies between affected herders and quarantine herders. For continuous variables, non-parametric Kruskal–Wallis tests were used to compare means among different groups (province, FMD status and species). Exchange rate used in the paper for cost calculations was US$1 = Mongolian Tugrik (₮) 2,462 - valid on 30 July 2018.

The relationship between herd-case duration and attack rates were assessed, in each species, using linear regression.

Socio-economic impact on herders

The following parameters were estimated in order to assess the socio-economic impact that herders faced as a consequence of the outbreak and control measures implemented: (a) impact on livestock assets; (b) impact on income due to forgone sales; (c) impact on herders' expenditure; and (d) impact on herders' food access and availability. Calculations were based on responses given by individual herders during the survey. Equations used are presented in the Table S1 For prices that were not collected during the survey, national statistics or average values estimated by local vets were used.

Impact on livestock assets

The difference between the number of animals showing clinical signs and culled was calculated. In addition, we estimated the proportion of animals culled in the herd, stratified by species, by dividing the number of animals culled by the sum of animals affected and animals not affected. To estimate the monetary impact on livestock assets due to mortality and culling, we considered the number of animals that herders reported either dead or culled as part of the control measures and the market prices (by province) provided by the Mongolian Statistical Information Service (MSIS) (Table S2). When assessing the impact due to culling, we considered two scenarios: before herders received compensation and after herders received compensation, which is 90% of the market value according to the regulations at the time of the survey. For those herders that had bought animals to replace those lost during the outbreak, we estimated the difference between prices paid and market price given by MSIS. Finally, for those that had not been able to buy animals the reasons for not being able to replace them are described.

Impacts on herders' income by foregone sales

The proportion of herders that were planning to sell animals or animal products but could not because of the outbreak and the control measures in place were estimates stratified by status (affected versus quarantined). For those that were not able to sell, monetary loss (during the outbreak and quarantine period) from selling live animals and milk was estimated considering the number of animals and litres of milk herders had planned to sell and the likely price they would have sold them. The price at which herders would have sold their animals (before the outbreak and after control measures are lifted) or milk was not collected as part of the survey; therefore, we used prices provided by the MSIS for live animals and the average price of milk estimated by local vets (₮1,000 per litre). Animal prices provided by MSIS do not consider changes on prices following a shock situation which might affect the supply of live animals. Therefore, price effect due to the FMD outbreak and control measures could not be estimated. Monetary loss for selling milk did not include forgone milk from dead or culled animals. Income foregone for selling wool or cashmere was not considered as only one herder reported planning to sell them.

Impact on herders' expenditure

First, we described the control measures applied by herders beyond the government measures and expenses incurred as a consequence of the outbreak and control measures applied. To estimate the economic impact on household expenditure, we considered the expenses herders incurred for buying milk and/or meat that they would not have bought if the outbreak (or control measures) had not happened, as well as the money spent on treating animals. To estimate additional expenditures for buying milk and meat, we used amounts and prices herders reported having paid for the milk and meat purchased. Treatment cost was the money herders reported spending for treating animals during the outbreak. Time spent treating animals or looking after animals was assumed to be part of the herders' daily duties and was not considered.

Impact on herders' food availability and access

First, we estimated the proportion of herders that reduced or ceased their milk or meat consumption and the length of time for which food consumption was affected stratified by herder status (affected versus quarantined) was assessed.

The extent to which milk and meat consumption (outcome variables) were interrupted in affected herders was associated with month or season when the herd-case started, province, herd-case duration and having dry meat storage (explanatory variables) was assessed using univariate logistic regression models. Herd-case duration was grouped into two categories using the median (6 days) as a cut-off. Quarantined herders were not included because data on month when the outbreak (or quarantine) started were not recorded in these herders. Variables with a p value $\le .1$ in the univariate analysis were assessed for collinearity and when present (Pearson correlation > 0.8) only the variable with strongest association with the outcome was kept in the model. Multivariable analysis was conducted using a backward stepwise elimination process with likelihood ratio tests used to select variables for inclusion in the final model.

Statistical analysis was performed in R 3.3.2 (R Development Core Team 2017) using packages car, lme4, lmtest and MuMIn.

2.3 | National gross economic losses

National-level gross losses due to reaction and expenditure in 2017 were estimated based on governmental data in a deterministic model. Data were provided for each affected province by the National Emergency Management Agency (NEMA), State Central Veterinary Laboratory (SCVL) and the General Agency Veterinary Service (GAVS, formerly the Veterinary Animal Breeding Association - VABA) on the costs related to the following aspects in relation to FMD outbreaks:

Reaction expenditure:

- Vaccines and vaccination included costs of the vaccines and delivery in order to vaccinate all susceptible animals (cattle, sheep, goats, camels and pigs) in the affected provinces.

- Diagnostics included diagnostic costs and laboratory consumables for testing samples from animals with clinical signs.
- Outbreak investigation and surveillance included the costs of staff attending outbreaks, the use of personal protective equipment and collection of samples.
- Compensation for culled animals (90% market value) based on the market price for live animals in each province (Table S2)
- Quarantine implementation included cost petrol, per diems for field vets and disinfectant per province.

Production losses.

- Mortality (due to deaths) based on the market price for live animals
- Compensation for culled animals (10% market value) based on the market price for live animals

For incorporating compensation costs, all paid and outstanding payments were included for outbreaks starting in 2017. Regulations indicated herders were to be compensated for 90% of the cost of the culled animals based on the market prices provided by the MSIS. The remaining 10% was incorporated into the national and provincial cost estimates of 'production losses' which also included the costs of animals that died for which farmers did not receive compensation. These costs were stratified by species (cattle, sheep, goats and camels) and age (0–1 years, 1–2 years and >2 years). No other production losses were considered because affected animals were either culled or died. The estimate attempted to capture the gross losses during the outbreak and subsequent control measures. Losses over time as a consequence of the outbreak were not considered. All the other costs (vaccines and vaccination, diagnostics, outbreak investigation and surveillance, compensation for culled animals (90% market value) and quarantine implementation) were combined into 'reaction and expenditure' at national and provincial levels.

3 | RESULTS

3.1 | Herder level

3.1.1 | Characteristics of herders included in the study

Data were collected from 112 herders made up of 70 (62.5%) affected herders and 42 (37.5%) quarantined herders between 10 May and 6 June 2018. As expected, the majority of the herders surveyed were nomadic (n = 97; 86.6%) and the remainder (n = 15; 13.4%) sedentary (i.e. have the same location all year round). All sedentary herders came from the relatively industrialized Selenge province (Figure 1c). Most herders (n = 89; 79.5%) kept a mixture of livestock species (cattle, sheep and goats) and 18 (16.1%) kept camels (in all cases along with other species). The most common reason given for keeping animals was as a source of meat for home consumption (99.1%), followed by selling live animals to generate income according to need (82.1%), producing milk (cattle, sheep and goats) to be consumed at home (78.6%) and slaughtering them at home and selling the meat (67.9%). Less common reasons for keeping animals were to produce milk and sell it (29.5%) and to sell animals on a regular basis (29.5%).

The median herd and flock sizes on the day of the interview (i.e. post-outbreak) were 27 cattle (1st quartile 14; 3rd quartile 54), 355 sheep (1st quartile 100; 3rd quartile 653), 195 goats (1st quartile 92; 3rd quartile 303) and 0 camels (1st quartile 0; 3rd quartile 0), with significant variation in herd and flock sizes between provinces (p < .001 for all species), but no statistical difference between affected and quarantined herders (cattle p = .63; sheep p = .68; goats p = .93; camels p = .15). However, when stratifying by province and FMD status, sheep flocks in Govisümber and Selenge and goat herds in Govisümber were significantly larger in quarantined herders compared with affected herds, while the opposite effect was found in cattle herds in Dungovi and goat herds in Tuv (Table 2; Figure S3).

Forty-five herders (40.2%; 26 affected herders and 19 quarantine herders) mentioned they did not know or understand the reasons for the implemented control measures of FMD, and most of those that understood the reasons had a veterinarian as a family member.

3.1.2 | Epidemiological characteristics of FMD outbreaks

Out of the 70 affected herds, the most common month for herd-case commencement was January (n = 17; 10 in January 2017 and 7 in January 2018), followed by September 2017 (n = 12), December 2017 (n = 10) and February 2017 (n = 8), which mirrors the pattern of disease spread observed in the country (Figure S2). The median herd-case duration was 6 days, ranging from 1 to 48 days with no significant difference between provinces (p = .15). Median attack rate was 31.7% in cattle, 3.8% in sheep and 0.59% in goats. The attack rate was higher in bovine calves than adults with the opposite trend reported in sheep and goats (Table 4). Herder-level attack rates were particularly high in Dornod, Selenge and Tuv provinces and low in Dornogovi and Khentii (Table 3). There was no significant relationship between attack rates and herd-case duration in any species (cattle p = .22; sheep p = .18; goats p = .72). None of the herders with camels reported clinical signs in this species, while the majority of herders (95.7%) had cattle, and all of them having cattle affected, with 51/70 (72.9%) only having cattle affected. Only 3 herders reported mortality in affected cattle which ranged from 6.4% to 41.2% in these 3 herds. There was no mortality reported in affected sheep and goats.

3.1.3 | Socio-economic impact of FMD outbreaks and control measures on herders

Impact on livestock assets

As part of the official control measures, animals with clinical signs of FMD were destroyed. In the majority of herds, the number of animals

TABLE 2 Herd and flock sizes on the day of the survey stratified by province and FMD status.

Province	FMD status	Number (% - from all herders in the study)	Number of nomadic herders	Cattle Median (1st–3rd qtl)	*p* value	Median (1st–3rd qtl)	*p* value	Goats Median (1st–3rd qtl)	*p* value	Camels Median (1st–3rd qtl)	*p* value
Dornod	AH	10 (8.9)	10	30 (29–212)	.38	555 (0–1154)	.38	240 (167– 253)	.56	0 (0–0)	.73
	QH	7 (6.3)	7	54 (16–103)		478 (168–600)		190 (86–255)		0 (0–0)	
Dornogovi	AH	10 (8.9)	10	28 (21–45)	.71	238 (170– 425)	.36	273 (174–363)	.22	10 (1–22)	.31
	QH	5 (4.5)	5	28 (14–48)		300 (250–650)		350 (310– 350)		0 (0–3)	
Dundgovi	AH	10 (8.9)	10	15 (8–22)	.02	506 (413–651)	.39	424 (316–567)	.18	0 (0–0)	.48
	QH	5 (4.5)	5	0 (0–0)		238 (68–1000)		213 (93– 260)		0 (0–0)	
Govisümber	AH	8 (7.1)	8	58 (46– 78)	.56	173 (0–375)	.04	75 (0–145)	.01	0 (0–0)	.77
	QH	5 (4.5)	5	45 (18– 56)		704 (372–1800)		581 (284–650)		0 (0–2)	
Khentii	AH	5 (4.5)	5	40 (17–51)	.25	400 (230–430)	.92	245 (150–285)	.75	0 (0–0)	.32
	QH	5 (4.5)	5	64 (56–65)		350 (250–662)		232 (178–240)		0 (0–0)	
Selenge	AH	10 (8.9)	0	8 (0–15)	.22	0 (0–0)	.04	0 (0–0)	.14	0 (0–0)	–
	QH	5 (4.5)	0	10 (9–22)		0 (0–2)		0 (0–3)		0 (0–0)	
Sükhbaatar	AH	10 (8.9)	10	46 (33–71)	.54	505 (170–703)	.67	195 (100–288)	.85	0 (0–0)	.30
	QH	5 (4.5)	5	37 (25–53)		450 (400–740)		100 (99–257)		0 (0–0)	
Tuv	AH	7 (6.3)	7	28 (18–31)	.33	650 (550–750)	.12	215 (170–275)	.02	0 (0–0)	–
	QH	5 (4.5)	5	15 (13–19)		180 (153–200)		120 (90–140)		0 (0–0)	
OVERALL		112 (100)	97	27 (14–54)		355 (101–653)		195 (92–303)		0 (0–0)	

Note: Information collected during the herders survey (n = 112) carried out between May and June 2018. Difference between affected and quarantine herds in each province was assessed using Kruskal–Wallis tests.

Abbreviations: AH, affected herders; QH, quarantined herders; qtl, quartile.

TABLE 3 Overall attack rate (%) stratify by species, age category and province

Province	Age category	Cattle Median (1st–3rd qtl)	*p* value	Sheep Median (1st–3rd qtl)	*p* value	Goats Median (1st–3rd qtl)	*p* value
All Provinces	Overall	31.7 (12.6–95.2)	.05	3.8 (0.74–6.6)	.29	0.59 (0–6.7)	.29
	Young stock	50 (20.9–100)		1.5 (0.34–11.1)		0.30 (0–1.4)	
	Adults	28.8 (10.0–100)		4.7 (0.89–8.1)		2.8 (0–6.7)	
Dornod	Young stock	100 (100–100)	.17	24.6 (22.3–26.9)	.32	30.2 (28.6–31.8)	.32
	Adults	72.1 (64.7–100)		3.1 (1.0–6.6)		11.9 (6.7–19.8)	
Dornogovi	Young stock	–	–	–	–	–	–
	Adults	5.7 (3.4–22.7)		4.8 (3.4–5.4)		0.54 (0.53–3.4)	
Dundgovi	Young stock	21.4 (10.7–31.4)	.39	1.9 (1.7–2.1)	.32	1.0 (0.8–1.3)	.32
	Adults	16.7 (12.5–21.7)		8.1 (4.6–8.9)		2.0 (1.5–2.4)	
Govisümber	Young stock	35.4 (33.3–50.0)	.41	–	–	–	–
	Adults	36.7 (11.4–47.9)		–		–	
Khentii	Young stock	0 (0–0)	.26	–	–	–	–
	Adults	5.9 (0.66–5.9)		–		–	
Selenge	Young stock	100 (100–100)	–	–	–	–	–
	Adults	100 (100–100)		–		–	
Sükhbaatar	Young stock	17.8 (4.9–30.4)	.37	0.69 (0.69–0.69)[a]	–	–	–
	Adults	12.5 (8.1–22.9)		–		–	
Tuv	Young stock	100 (100–100)	–	–	–	–	–
	Adults	66.7 (32.1–88.8)		100 (100–100)		–	

Note: Data were collected between May and June 2018 (n = 112). Difference between young stock and adults were assessed using Kruskal–Wallis tests.

[a]Only one flock affected; qtl = quartile.

culled was the same as those showing clinical signs, although a small number of herders (n = 4; 5.7%) reported having animals with clinical signs not destroyed, and some herders (n = 10; 14.3%) had animals without clinical signs culled. This was consistent with national-level data. The median proportion of cattle, sheep and goats culled in the herd or flock was 30%, 1% and 0.5%, respectively. Estimated median loss for animals culled before receiving compensation was ₮4,818,000 (US$1,956) and ₮481,800 (US$185.7) once herders received compensation (Tables 4 and 5).

At the time of the survey, most herders (92.9%) reported that they had not been able to replace all animals that were culled as part of the control measures, while the rest (7.1%) had only been able to replace some of the animals lost. The prices of these replacement animals ranged from ₮200,000 to ₮1,500,000 (median ₮325,000; US$132.01) in cattle, between ₮40,000 and ₮70,000 (median ₮50,000; US$20.31) in sheep and between ₮30,000 and ₮50,000 (median ₮40,000; US$16.25) in goats, which were on average half the market price estimated for adult animals by the MSIS. The main reasons given for not replacing these losses were lack of money and delays in receiving financial compensation for destroyed animals. Only four (5.7%) herders had received compensation at the time of the survey. These herders were affected in January and February 2017, and compensation was received between June and July 2017. Herders with only adult cattle affected (3 out of 4) received between ₮435,500 (US$176.89) and ₮500,000 (US$203.09) per animal, while the herder with 2 adult cattle and 13 calves affected received ₮2,000,000 overall (₮133,333 average per animal; US$54.16).

Impact on herders' income due to forgone sales

Reduction in the sale of animals was reported by some herders. Half of the affected herders and a third of the quarantined herders were not able to sell animals or animal products that had planned to sell and would have been sold if the outbreak had not occurred (Table 4). For those herders that were planning to sell live animals, the median income foregone from sales of live animals (during the outbreak and control measures) was ₮8,406,500 (US$3,414) for affected herds and ₮5,003,500 (US$2,032) for quarantined herds, while for those planning to sell milk the median income forgone was 1,200,000 (US$487) for affected herds and ₮3,000,000 (US$1,218) for quarantined herds (Table 5).

Impact on herders' expenditure

Among both affected and quarantined herders, almost half of herders interviewed (n = 48; 42.8%) did not apply any measures to protect non-affected animals beyond the government enforced quarantine. Over a third (n = 43; 38.4%) kept animals isolated, ten (8.9%) reported having animals vaccinated by the government (from which 5 were affected herders and 5 quarantined herders, all of them from Dornogovi province) and four (3.4%) treated animals with antibiotics as a preventive measure. The remaining herders (6.5%) reported

TABLE 4 Impact of FMD control measures on herders' livelihoods and food security in Mongolia

	Quarantined herders *n* = 42	Affected herders (*n* = 70)	*p* value
Impact on livestock assets			
Number of animals culled in the herds/flock		Median (min–max)	
Cattle		6 (0–300)	
Sheep		0 (0–70)	
Goats		0 (0–0)	
Camels			
Percentage of the herd culled			
Cattle		30.0% (12.5%–100%)	
Sheep		0.94% (0%–100%)	
Goats		0.53% (0%–29%)	
Camels		0% (0%–0%)	
Forgone sales	Number (%)	Number (%)	
Affected plans to sell animals or animal products	15 (35.7)	35 (50.0)	.20
Number of live animals planned to sell[a]	Median (min–max)	Median (min–max)	
Cattle	0 (0–20)	0 (0–15)	.38
Sheep	0 (0–50)	0 (0–300)	.47
Goats	0 (0–20)	0 (0–190)	.69
Animal products planned to sell[a]			
Milk (litres)	0 (0–4800)	0 (0–4800)	.50
Wool (Kg)	–	130[b]	–
Cashmere (Kg)	–	130[b]	–
Impact on food access and availability	Number (%)	Number (%)	
Did not drink any milk for a period of time	32 (76.2)	54 (77.1)	1
Did not eat meat for a period of time	7 (16.7)	12 (17.1)	1
Reduced milk consumption for a period of time	7 (16.7)	8 (11.4)	.62
Reduced meat consumption for a period of time	16 (38.1)	22 (31.4)	.61
Purchased milk from elsewhere	3 (7.1)	7 (10.0)	.74
Purchased meat from elsewhere	0 (–)	11 (15.71)	.006
	Median (min–max)	Median (min–max)	
Days drank less milk	21 (14–90)	30 (14–60)	.48
Days bought milk (that had not planned to buy)	60 (45–150)	45 (15–60)	.26
Days ate less meat	30 (20–60)	26 (21–30)	.61
Other impacts			
School close during control measures	6 (14.3)	13 (18.6)	.75
Could not visit family	6 (14.3)	19 (27.1)	.18
Could not receive visitors	20 (47.6)	39 (55.7)	.53
Family members could not get back home	5 (11.9)	10 (14.3)	.94
Borrow money to buy food	9 (21.4)	34 (48.6)	.008
Borrow money to buy animals	0 (–)	8 (11.4)	.02
Borrow money to buy medicines	7 (16.7)	23 (32.9)	.10
Borrow money to pay bills and bank loans	10 (23.8)	21 (30.0)	.62
Borrow money to pay school fees	4 (9.5)	13 (18.6)	.28

Note: Data were collected between May and June 2018 (*n* = 112). Difference between affected and quarantine herds were assessed using Fisher's exact or chi-squared tests for categorical variables and Kruskal–Wallis tests for continuous variables.

[a]From those that had planned to sell animals or animal products.

[b]only 1 herder reported having plans to sell wool and cashmere.

TABLE 5 Monetary impact of FMD control measures on herders in Mongolia

	Affected herders Median (1st–3rd qtl)	Quarantined herders Median (1st–3rd qtl)
Impact on assets (livestock numbers)		
Loss due to mortality (*n* = 3)	4,860,000 (2,880,000–4,905,000)	–
Loss due to culling (before compensation is received)	4,818,000 (1,686,750–15,007,238)	–
Loss due to culling (once compensation is received)	481,800 (168,675–1,500,724)	–
Impact on income (forgone sales during the quarantine period)[a]		
Money loss from animals that could not be sold (*n* = 17)	8,406,500 (3,150,000–15,413,250)	5,003,500 (2,383,688–10,328,938)
Money loss from milk that could not be sold (*n* = 19)	1,200,000 (45,000–1,500,000)	3,000,000 (2,370,000–3,450,000)
Impact on herders' expenditure		
Extra expense for buying milk (*n* = 7)[b]	32,750 (25,125–49,500)	56,000 (40,500–140,500)
Extra expense for buying meat (*n* = 11)	210,000 (4,900–275,000)	–
Treatment cost (*n* = 8)[c]	18,000 (15,500–19,000)	82,000 (42,000–100,000)

Note: Data were collected between May and June 2018 (*n* = 112).

[a]Only herders that were planning to sell animals or milk were considered.

[b]10 reported to buy milk but only 7 gave prices.

[c]Only animals that spent in treatment were considered.

using an alternative approach such as fumigating with some plants, washing with disinfectant or moving to another location. No significant differences were found between affected and quarantined herds on the application of control measures to animals that were not affected. Median treatment cost was higher for quarantined herds ₮82,000 (US$33.) than for affected herders ₮18,000 (US$7.3) ($p$ = .04). For herds that treated with antibiotics and reported the length of treatment and cost (n = 4; 3 affected herds and 1 quarantined herd), the treatment lasted between 1 and 7 days (average 3.3 days) and the overall cost ranged between ₮13,000 and ₮20,000 (US$5.28-US$8.12) per herd.

Seven (10%) affected herders and three (7%) quarantined herders purchased milk. Seven (out of ten) provided prices of milk purchased, the median cost of milk reported was ₮40,000 (US$16.2) per litre (min ₮24,000 max ₮225,000), with quarantined herders spending more than affected herders (Table 5). Eleven out of 70 (15.7%) affected herders reported purchasing meat or meat products during the outbreak, a practice that was otherwise uncommon and therefore, emphasizing their reliance on markets for food: only four (5.7%) herders reported regularly buying meat before the outbreak. The median monetary impact on household expenditures from buying meat was ₮210,000 (US$85.3) Table 5. None of the quarantined herds reported purchasing meat or meat products during the quarantine.

Impact on herders' food availability and access

In terms of food security, household (physical) food access and availability were reduced in both affected and quarantined herders and their families. More than two thirds of herders (and herders' families) did not drink milk for a period of time (median 45 days for both groups, range 7 to 120 days in affected herders and 21 to 90 days in quarantined herders; p = .77) or had to reduce milk consumption (median 30 days for affected herders—min 14, max 60 days, and 21 days for quarantined herders—min 14, max 90 days; p = .48). Milk and meat consumption before or after the outbreak were not recorded, and therefore, differences in consumption at differences points in time were not estimated. Empirical observations suggest that reduced consumption among quarantined herders is due to the belief that consumption of animal products might be unsafe while in the quarantine period regardless if their herd was affected or not. Notably, the median periods without drinking milk and reduced milk consumption were longer than the mean herd-case duration. In both groups, a sixth of herders and their families did not eat meat for a period of time and a third reduced their meat consumption for at least 20 days (Table 5). Informal observations suggest that food substitution would be low given the nomadic lifestyle of herders and limited availability of other sources of food such as crops although food substitution was not systematically recorded.

Examining milk and meat consumption more closely, herders that reported having stored dried meat (i.e. had some meat savings to cushion them) were less likely to stop (p = .04) or reduce (p < .001) meat consumption for a period of time. Province was not included in the multivariable analysis as the model failed to converge. For affected herders, herders were significantly more likely to have their meat consumption reduced when the herd-case started in

TABLE 6 Final multivariable logistic regression model for identification of factors associated with reduction in meat consumption during the FMD outbreak and control measures in place

Factors	OR	95% C.I.	*p* value
Month herd-case started			
January	*ref*		*ref*
February	3.07	0.10–90.30	.46
March	10.33	0.30–387.8	.16
April	17.81	0.44–1,014.87	.11
July	3.35	0.11–106.33	.44
August	13.23	0.85–400.56	.08
September	24.85	3.13–548.57	.008
October	63.08	2.97–3,202.18	.01
November	6.12	0.47–153.73	.18
December	6.38	0.66–145.29	.14
Had dry meat storage			
No	*ref*		*ref*
Yes	0.32	0.07–1.26	.11

Note: Univariate models are presented in the supplementary material.
R^2 = .38.

September or October (i.e. before the winter) compared to those affected in January, even after adjustment for storage of dried meat in the household (Table 6). No statistically significant patterns were found between milk consumption and time of the year when the herd was affected. (Tables S3 and S10). Time of the year when the quarantine was put in place was not recorded, and therefore, the effect between months when quarantine started could not be assessed on quarantined herders.

Other impacts on herders' livelihoods

Borrowing money was a common coping strategy, representing a household income shift from livestock to use of credit. More than half (57.1%) of affected herders and more than a third (35.7%) of quarantined herders had to borrow money for reasons including buying food, buying medicines for family members and paying bills and bank loans. Affected herders were significantly more likely than quarantined herders to borrow money for buying food (p = .008) and/or buying animals (p = .024) (Table 4). The places that herders borrowed money from was not systematically recorded.

Other negative impacts on herders as a consequence of the control measures included not being able to receive visitors, afford school fees, school closures and household members not being able to return home (Table 4).

3.2 | National level

Provinces reporting clinical cases are illustrated in Figure 1c. The number of animals culled, attack rates and mortality rates stratified by province and species are presented in Table 7. The majority

TABLE 7 Official number of cattle, sheep, goats and camels in each FMD affected province in Mongolia during 2017 with the number of FMD cases and deaths due to disease

	Number of animals				Cases (attack rate, %)				Deaths (fatality rate, %)			
Province	Cattle	Sheep	Goats	Camels	Cattle	Sheep	Goats	Camels	Cattle	Sheep	Goats	Camels
Dornod	207,861	1,001,567	592,083	5,579	1,182 (0.57)	123 (0.01)	132 (0.02)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Dornogovi	72,620	861,478	893,603	40,724	290 (0.40)	53 (0.01)	108 (0.01)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Dundgovi	75,277	1,686,203	1,634,553	36,792	104 (0.14)	364 (0.02)	306 (0.02)	10 (0.03)	0 (–)	0 (–)	0 (–)	0 (–)
Govisümber	14,903	205,229	195,077	929	17 (0.11)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Khentii	335,295	2,212,453	1,545,305	4,198	384 (0.11)	56 (0.003)	9 (0.001)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Selenge	218,403	699,295	496,273	507	1538 (0.7)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Sükhbaatar	236,792	1,815,324	1,152,392	8,325	3,058 (1.3)	767 (0.04)	348 (0.03)	0 (–)	43 (1.4)	0 (–)	0 (–)	0 (–)
Tuv	310,761	2,461,124	1,534,158	3,528	771 (0.25)	84 (0.003)	20 (0.001)	0 (–)	1 (0.1)	0 (–)	0 (–)	0 (–)

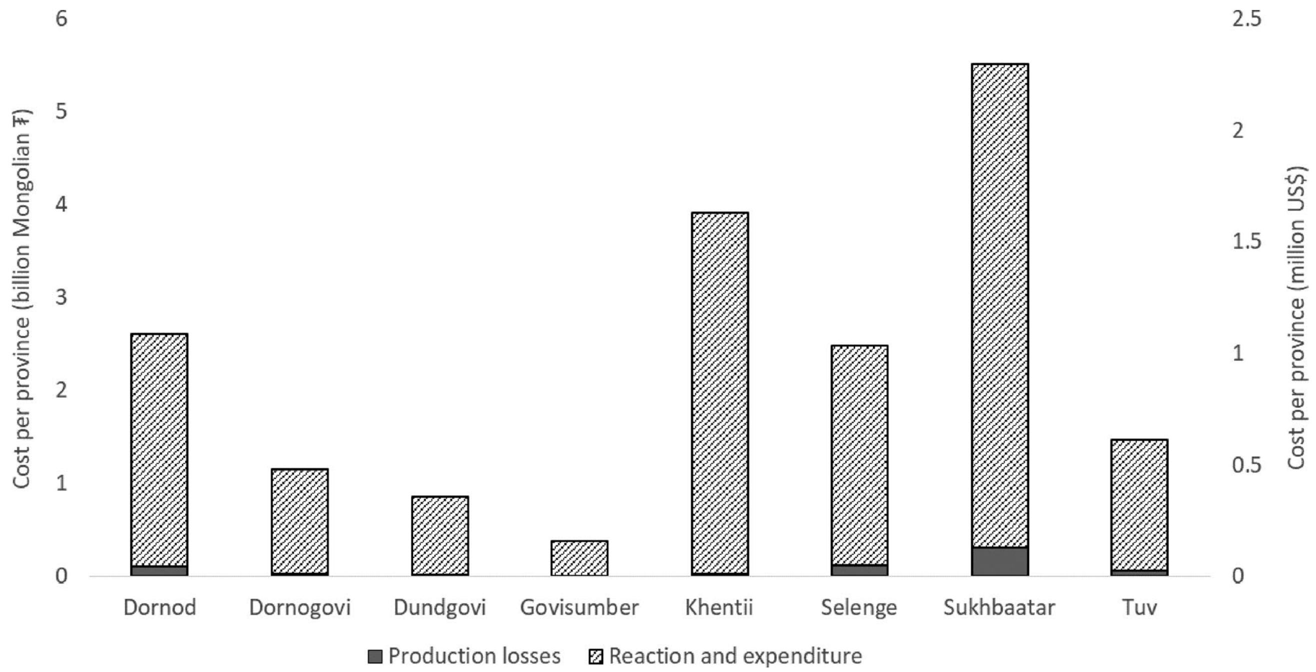

FIGURE 2 Provincial level costs of FMD outbreaks in 2017 in Mongolia represented as production losses and due to reaction and expenditure

of cases were in Sükhbaatar province, which also had the highest attack rate for cattle (1.3%), sheep (0.04%) and goats (0.03%). The mean province attack rate was highest in cattle at 0.45% compared to 0.01% in sheep and 0.01% in goats. In Selenge province, there were 10 reported cases in camels (attack rate 0.03%) although there were no other reports of FMD in camels in the other provinces. Deaths due to FMD were only reported among cattle in Sükhbaatar and Tuv provinces with case fatality rates of 1.4% (43/3058) and 0.1% (1/771), respectively.

The overall national-level gross losses for outbreaks starting in 2017 was ₮18.4 billion equivalent to approximately US$7.35 million. The majority of the cost (₮17.7 billion, 96.4%) was due to reaction and expenditure (Figure 2), from which ₮10.4 billion (59%) was due to vaccination: ₮4.4 billion (25%) due to compensation, ₮2.8 billion (16%) due to quarantine cost and the rest (0.86%) due to diagnostic and surveillance. The costs were highest in Sükhbaatar province which made up 30% of the total national cost.

4 | DISCUSSION

The study provides the first assessment of the impact of FMD control measures in Mongolia including a quantification of the national expenditure and the implications for herder livelihoods and food security. To our knowledge, no previous estimates on the impact of FMD official control measures on herders' (or farmers) livelihoods exist. Although focusing on Mongolia, the findings and approach are relevant to other FMD endemic regions aiming to control the disease particularly those following the Progressive Control Pathway for FMD (PCP-FMD) (FAO, 2018).

The median attack rate in cattle in this study was lower than in other endemic settings (Jemberu et al., 2014; Lyons, Alexander, et al., 2015; Lyons, Stärk, et al., 2015; Vu et al., 2017), which could be attributed to the production system, virus strain, differences in level of immunity and the (modified) stamping out policy in place. Detailed assessment of the attack rates revealed a high variation in attack rates between provinces although there was no strong statistical evidence to support this observation. Some of this variation can be explained by differences in production systems and different levels of immunity from previous vaccination. Herds in Selenge are kept in confined spaces in sedentary (fixed) locations, and therefore, contact rates are likely to be higher than in nomadic herds; in addition, herds in Selenge were not vaccinated as part of the national campaigns in 2016 possibly explaining the higher attack rates in this province. In contrast, cattle in areas considered higher risk in the other seven Eastern provinces were vaccinated in June and October 2016. It is therefore possible that some of the affected herders were not in a high-risk area and therefore were not vaccinated. Future studies should collect vaccination status and type of vaccine used at herder level. Outbreaks during the year showed a seasonal pattern with more outbreaks happening in January and between August and October, suggesting revising vaccination times and coverage may have positive benefits on reducing the number of outbreaks if the pattern was consistent with previous years.

Our study showed that the current FMD control measures have important negative consequences for Mongolian herders. Some herders and their families went without drinking milk for longer than a month, with affected herders up to four months and quarantine herders up to three months. This suggested that the negative effects can last longer than the herder-case duration and the official quarantine period. A similar effect was observed with meat consumption with some herders having a reduced meat consumption for up to a month in the case of affected herders and up to two months in the case of quarantined herders. Crucially, the livelihood and food security of all herders within a quarantine zone, including those without clinical disease in their herds and flocks, was seriously impacted. Although the negative impact on herders with animals showing clinical disease can be expected, the collateral damage to farmers that fall in the quarantine zone is usually ignored and has not been previously quantified. In interpreting our results, it is important to consider that these parameters are herders' estimates and recall or reported bias cannot be excluded. The study may have been considered an opportunity to obtain support, and as a result, the negative effect on meat and milk consumption might have been overstated. Longitudinal studies to capture differences on consumption and management practices (such as selling as slaughter rates) during the year and over time should be conducted in the future to better understand patterns without the disease or control measures. Nonetheless, the information recorded and reported here is valuable baseline information that illustrates the negative impact and can be used in further studies. Some quarantined herders reported avoiding the consumption of animal products from their farms as they perceived them as unsafe to consume, highlighting some of the misunderstanding that might arise during disease control programmes and the need for effective communication among stakeholders at different levels.

An important seasonality effect was observed, with herders' meat consumption more likely to be affected if the outbreak happened before the winter. This outbreak timing is likely to have a greater negative impact on the ability to store dried meat which is commonly done in Mongolia in preparation for hostile winter conditions. However, month when animals are affected (i.e. month when herd-case starts) and having meat stored only explained a third of the variance and so other factors that were not recorded in this study might also play a role in reducing meat consumption. Furthermore, the wide confidence intervals observed in some of the months reflect the variation on the data and the relatively small sample size. Outbreak timing (or another shock situation) has been identified elsewhere as an important factor linked to food stability (Limon et al., 2017)—a food security component that highly depends on the resilience of the household to cope with adverse situations. In contrast to subsistence farmers in other parts of the world, where production diversification is part of farmers' strategy to deal with variability in production (Ellis, 2000; Randolph et al., 2007), herders in Mongolia rely almost entirely on livestock for food and financial security with very limited options for food substitution (Jamiyan, 2017a), reducing their resilience in the face of high impact disease outbreaks. As a result, available coping strategies to deal with food scarcity are limited, resulting in the majority of the herders incurring extra expenses or accruing debt. For children, not only was their food security compromised but there were further negative effects through temporary lack of schooling and absence of family members. Formally quantifying food substitution and available options for borrowing money should be explored in more detail in the future to better understand the impact and safety nets that herders might have available.

The unintended negative effects of the current FMD control policy in Mongolia identified in this study is at odds with the sustainable development agenda (United Nations, 2015) and the Mongolian national policy to tackle food insecurity and malnutrition (Jamiyan, 2017a, b). However, the research has also identified ways of ameliorating the negative effects. For example, enhanced food support for affected and quarantined herders in parallel with the current FMD control strategy, especially if the outbreak happens in the months before winter, to safeguard nutritional needs of herders and their families. A limitation of this study is that food substitution and food utilization, specifically repartition of food available within the household, was not assessed. In addition, data to capture the perception by gender and differences on how men and women were affected were not collected. It is therefore possible that the extent to which food security is compromised among different household members might differ. Further studies should investigate this and the nutritional implications among different household members, especially pregnant women and children. Macro-level evaluation of food security (market stability) was beyond the scope of this study. Similarly, effect on market prices due to changes in supply and demand of live animals was not estimated. Herders planning to sell livestock during the outbreak or quarantine period may have delayed the sale rather than foregone revenue completely. Therefore, the estimated loss is the gross loss and could be an overestimate. The effects of the current policy over time should be evaluated and quantified in the near future to get a better understanding of the overall collateral effects and benefits.

Most of the herders (94.3%) interviewed had not received compensation at the time of the study, resulting in direct negative impact on herders livelihoods by decreasing herd size and production and increase herders' debt and expenditure. Furthermore, half of the herders did not know or understand the reasons for the control measures and there was some misunderstanding regarding the safety of milk. Similar situations in other countries have led to lack of trust in the veterinary services and non-compliance (Elbers, Gorgievski, Zarafshani, & Koch, 2010; Limon et al., 2014; Smith, Bennett, Grubman, & Bundy, 2014). Concerns about herders reporting new cases and fully implementing animal movement restrictions were highlighted in a previous risk assessment identifying strength and weakness of the Mongolian FMD control system (Wieland, Batsukh, Enktuvshin, Odontsetseg, & Schuppers, 2015). Hence, providing compensation in a timely manner, putting in place procedures to reduce the negative impact of the control measures to herders and improving risk communication should reduce the negative impact on herders' livelihoods and maintain institution credibility.

The estimate of gross economic loss at national level was US$7.35 million, which equates to approximately 0.65% of the Mongolian GDP. Although the current control policy had reportedly controlled sporadic outbreaks in previous years, the outbreaks in 2017 were much more widespread with greater numbers of herders and animals affected (Figure S2). It is important for any country implementing disease control measures to evaluate the policy against defined objectives to ensure optimal use of resources. Figure 2 shows the expenditure on reaction far outweighs the production losses which is expected with the current control policy. Similar results have been reported in other FMD outbreaks (Thompson et al., 2002). Only the gross costs of the current control policy (within one year) were estimated, and the benefits of indirect costs on reducing the overall impact over time were not assessed. Moreover, a net estimate that incorporates the cost of keeping animals (e.g. feed) was not included. Simulation models to evaluate different control scenarios in order to determine the most likely cost-effective policy should be done in the near future. The model developed in this study could be extended to a full cost–benefit analysis which can be used to inform policy.

5 | CONCLUSION

This study described and quantified the unintended consequences of FMD control measures on herders' income, extra expenditure and debt, and food availability and access; and estimated the national-level gross losses attributable to the outbreak in 2017. Thorough analysis of our findings has revealed possible strategies that could be employed to ameliorate the negative effects of the current control policy.

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CONFLICT OF INTEREST

The authors declare no competing interest. Co-authors working for the State Central Veterinary Laboratory or the Veterinary and Breeding Agency in Mongolia helped to provide and coordinate data collection but did not have a role in the analysis and interpretation of the data.

ETHICAL APPROVAL

Ethics approval was obtained from the State Central Veterinary Laboratory in Mongolia and the Social Science Research Ethical Review Board at the Royal Veterinary College (URN SR2019-0145). All activities were conducted in accordance with protocols approved by this board.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Georgina Limon https://orcid.org/0000-0001-6230-2475
Mieghan Bruce https://orcid.org/0000-0003-3176-2094
Philippa M. Beard https://orcid.org/0000-0002-2285-810X
Nicholas A. Lyons https://orcid.org/0000-0002-5847-8707

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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